TRANSIENT LIQUID WATER AS A MECHANISM FOR INDURATION OF SOIL CRUSTS ON MARS.

G. A. Landis,[1] D. Blaney[2], N. Cabrol[3], B. C. Clark[4], J. Farmer[5], J. Grotzinger[6], R. Greeley[5], S. M. McLennan[7], L. Richter[8], A. Yen[2], and the MER Athena Science Team, [1]NASA John Glenn Research Center, mailstop 302-, 2000 Brookpark Road, Cleveland, OH 44135; geoffrey.a.landis@nasa.gov, [2]Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109; [3] NASA Ames, Moffett field, CA; [4]Lockheed-Martin Corporation, Denver CO [5]Arizona State University, Tucson, AZ; [6]Massachussetts Institute of Technology, Cambridge, MA; [7]SUNY at Stony Brook, Stony Brook, NY; [8]DLR, Germany

Introduction: The Viking and the Mars Exploration Rover missions observed that the surface of Mars is encrusted by a thinly cemented layer tagged as "duricrust" (figure 1). A hypothesis to explain the formation of duricrust on Mars should address not only the potential mechanisms by which these materials become cemented, but also the textural and compositional components of cemented Martian soils. Elemental analyzes at five sites on Mars (Viking [1], Pathfinder [2] and MER [3]) show that these soils have sulfur content of up to 4%, and chlorine content of up to 1%. This is consistent with the presence of sulfates and halides as mineral cements [4]. For comparison, the rock "Adirondack" at the MER site, after the exterior layer was removed, had nearly five times lower sulfur and chlorine content [3], and the Martian meteorites have ten times lower sulfur and chlorine content, showing that the soil is highly enriched in the salt-forming elements compared with rock.

At both MER sites, duricrust textures revealed by the Microscopic Imager show additional textural features that need too be considered in any general model that attempts to account for their origin. These features include the presence of fine sand-sized grains, some of which may be aggregates of fine silt and clay, surrounded by a pervasive light colored material that is associated with microtubular structures and networks of microfractures (figure 2). Stereo views of undisturbed duricrust surfaces reveal rugged microrelief between 2-3 mm and minimal loose material. Comparisons of microscopic images of duricrust soils obtain before and after placement of the Mossbauer spectrometer indicate differing degrees of compaction and cementation at the two MER sites.

Here we propose two alternative models to account for the origin of these crusts, each requiring the action of transient liquid water films to mediate adhesion and cementation of grains. Two alternative versions of the transient water hypothesis are offered, a “top down” hypothesis that emphasizes the surface deposition of frost, melting and downward migration of liquid water and a “bottom up” alternative that proposes the presence of interstitial ice/brine, with the upward capillary migration of liquid water. The viability of both of these models ultimately hinges on the availability of seasonally transient liquid water for brief periods during the Martian year.

Duricrust Formation: At the elevation of the landing sites of all Mars missions to date, including the Mars Exploration Rovers, the atmospheric pressure lies above the triple point pressure of liquid water. At night, soil and rock temperatures are cold enough (e.g., about -100C at the Gusev site) to allow a small amount of water to condense on or between the grains. In the "top down" model, this deposited frost is warmed by the daytime temperature rise to form a transient liquid phase, which migrates downward (assisted by capillary action), in the process dissolving any salt present. Surface tension in the liquid pulls the gains together. As the soil heats further, the water evaporates, and the remaining salts cement the grains to form the duricrust. New aeolean dust and sand brings further material to the site, allowing the surface crust layer to thicken.

In the alternative “bottom up” hypothesis, as sunlight warms the soil during the day, liquid from a subsoil brine or ice reservoir is drawn upward by capillary forces toward the surface, where it evaporates, depositing any dissolved salts present.

Figure 1: a view of the track of the Spirit rover, showing small rocks pressed through the crust layer by the rover wheel.

In both cases, dissolved salts and capillary-pore effects [5] will tend to extend the liquid range of the water, allowing the process to operate over a wider range of temperatures.

Repetition of this process over long time spans could produce a coherent zone of cementation. These models, which emphasize interactions between the atmosphere and soils, appear to be quite plausible under present Martian climatic/atmospheric conditions and could explain the apparently widespread distribution of cemented soils on Mars, over a broad range of elevations latitudes. Variations in the length of time a transient liquid water phase is present each year would ultimately determine the presence and thickness of cementation. However, the thickness of duricrust accumulation must also be balanced against destructive processes, such as Aeolian deflation.

This integrated model offers an explanation for the process of cementation, its widespread distribution and compositional and textural features of crusts (e.g. presence of microtubules, a pervasive light-colored "matrix" observed under MI; the enrichment in sulfur and chlorine, indicated by APXS). The implied presence of sulfates and chlorides, both common evaporite minerals may be compared with potentially analogous settings on Earth (e.g. cemented playa surfaces and duricrusts of terrestrial deserts).

Liquid water processes will tend to leech and concentrate salts in some places, while impacts and aeolian processes would redistribute them. This would provide a constant source of salts as newly accreted fine materials: Unlike Earth, salts on Mars most likely have not been highly mobilized by water. Salt will thus be likely to be widely distributed across the surface.

The liquid phase need not occur regularly. The age of the surface crust is not well constrained, but the transient water mechanism could operate even if the conditions for a liquid phase exist only at rare and widely-separated intervals. Electrostatic agglomeration may also work to agglomerate micrometer-scale dust particles into larger units before the cementing.

Differences between the crust at the Gusev and Meridiani sites yield further evidence and some constraints for cementation mechanisms. Further constraints on the origin of these Martian duricrusts should come from examination of the subsurface that can be exposed by the rover wheels during driving or during deeper trenching activities.

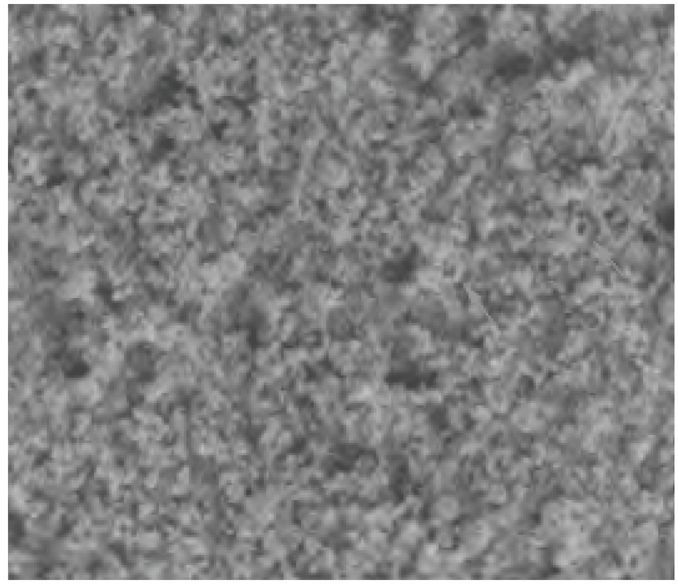

Figure 2: Microscopic Imager photograph of soil at Spirit landing site in Gusev crater.

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